Diploma
Examinations
Program

Physics 30 Program
Machine-Scorable Open-Ended Questions

Units 1-5: Complete Course

Students
First !

Student Evaluation
and Records

Alberta
EDUCATION

September 1989

TABLE OF CONTENTS

PREFACE

This document outlines the use of machine-scorable open-ended questions in the evaluation of Physics 30. It is primarily designed for use by classroom teachers of Physics 30, though it can be modified for use by teachers of Physics 10 and Physics 20. The sample items provided were originally asked in multiple-choice form on Grade 12 Diploma Examinations.

The use of machine-scorable open-ended questions is being considered for the 1991 series of Diploma Examinations in Physics 30, and such questions are being introduced on the 1990 field tests. Students writing these field tests should be made familiar with the use of this item format.

The document can also be used for professional inservice at the school or jurisdiction level. In this case, supplementary materials suitable to local needs could be added to the basic foundation provided here.

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INTRODUCTION TO MACHINE-SCORABLE OPEN-ENDED ITEMS

It is now possible to have students derive the answer to an item and record the answer in a machine-readable form. Final answers can be expressed as a single number or as a sequence of numbers. This item format can be used as an alternative to multiple-choice, to sequencing, or to matching formats. Alberta Education uses the following guidelines for the construction of machine-scorable open-ended items:

- Solutions to machine-scorable open-ended items should be short and involve no more than one or two steps.
- All legitimate methods of solving a problem should lead to numerical answers that are marked correct.
- In general, each item should have the same weighting as a multiple-choice item.

Compared with multiple-choice items there are the following benefits:

- The chances of a student guessing an answer correctly is essentially reduced to zero.
- Answer verification methods are eliminated as students cannot work backwards from the alternatives provided.
- Students cannot determine the correct answer by eliminating the other distractors.
- Students cannot obtain additional clues from the list of possible responses presented.
- Machine-scorable open-ended items individually discriminate very well between strong and weak students at all difficulty levels.
- When these items are included on a test, the test as a whole will be more reliable in ranking the students from strongest to weakest.

However, the following limitations still apply:

- The effectiveness of this type of item has not yet been tested for subjects other than mathematics.
- Answer fields suitable for this type of Physics 30 item may be too complex for use.

Alberta Education has used machine-scorable open-ended questions successfully since January 1989 in its Mathematics 30 Diploma Examinations. The mathematics questions used a four space answer field, accommodating numbers between 0.1 and 999.9. All input numbers were presumed exact, and all numerical answers were required to be rounded to the nearest tenth. A standardized rounding instruction had to be given. Students were told to keep their calculators running for the whole item. When this instruction was given, multiple answers were eliminated.

In introducing machine-scorable open-ended questions to Physics 30 there are four main problems:

- Physics questions do not have answers that limit to the numerical range from 0.1 to 999.9. Allowance must be made for the use of scientific notation and metric prefixes.
  Possible solution: For numerical answers between 0.01 and 99.99 SI base units, there are no difficulties if the decimal is placed between the second and the third columns of the answer field. For numerical answers between 0.01 and 99.99 SI base units, there are no difficulties. We will use the prefixes *kilo*, *centi*, and *milli* freely, and will attach them to any SI base unit. The prefixes *mega* and *nano* will be restricted to common usages such as megahertz (MHz) and nanometre (nm). No other prefixes will be used in machine-scorable open-ended questions. We will express other large and small numbers in scientific notation, and will ask for either the numerical factor or the exponent. To allow for three digit accuracy in the numerical factor, the decimal point is placed between the second and the third columns of the answer field.

- Most numbers used in physics calculations are not exact, and answers obtained must reflect the proper use of significant digits.
  Possible solution: Machine-scorable open-ended questions can be used as a rigorous test of the proper use of significant digits, but that is not the intention here. In most questions, it will be obvious how many digits are called for. In those questions where it is not obvious, allowance for variations will be made in the key.

- Multiple answers cannot be completely eliminated, as the *Data Booklet* is of three-digit accuracy, and the use of different constants or equations as starting points automatically gives final answers that can differ by two or three in the third digit.
  Possible solution: We find more multiple answers in the Structure of Matter unit than in any other. All such answers could be eliminated if a five digit *Data Booklet* were used. However, the use of three digit input data is customary in physics teaching. Consequently, answer keys must allow for multiple answers. On the other hand, the keys do not allow for answers generated by premature internal rounding.

- Answers expressed in scientific notation to three-digit accuracy really need six spaces in the answer field, three to accommodate the numerical factor, one for the sign of the exponent, and two for the exponent.
  Possible solution: Six-space answer fields might prove too difficult to use, and the mixing of two or three different answer fields in a seven or twelve question section is undesirable. Therefore, for questions whose full answers require the use of scientific notation, we will use the following format:

  The force is $b \times 10^{w}$ N when expressed in scientific notation.
  The value of b (or of w) is ____________.

The items

The 30 items were originally asked in multiple-choice form on previous Physics 30 Diploma Examinations. The Item Information Sheet on pages 20 and 21 shows the item difficulties of the individual questions as tested. When reading this table, bear in mind that the difficulties of easy questions are above 0.750, of average questions between 0.550 and 0.750, and of difficult questions are below 0.550. It is probable that all items will be more difficult when asked in machine-scorable open-ended form.

The items illustrate answers that are numbers expressed to both two and three significant digits. For answers such as 1.47×10^{-17}, some questions call for the 1.47, while others call for the 17 in the exponent.

Other items are included to illustrate the presence of two or more valid answers. All valid answers are included on the Item Information Sheet on pages 20 and 21, with only the most common answer included on the answer sheet on pages 31 and 32. In working out the answers, we have not rounded any intermediate answers. Explanations of the allowed variations in the answers are found on pages 22 to 30.

Using the items

The items can be used as review sheets for physics content, or as practice items for the question format. It is not appropriate to use the complete set as a test, since the items were selected to illustrate the use of significant digits, the presence of valid multiple answers, the use of scientific notation, and the recording of partial answers. The set does not constitute a selection of typical physics problems that can be used as a comprehensive test in Physics 30.

Field Tests in Physics 30

All field tests in Physics 30, starting in January 1990, will contain machine-scorable open-ended questions. The instruction page used in these field tests is shown on page 4. Teachers are encouraged to share the contents of this document with their students before the field tests are administered. The form in which machine-scored open-ended questions appear on future Diploma Examinations largely depends on the results of the 1990 field tests.

SAMPLE INSTRUCTION SHEET (FOR MACHINE-SCORABLE OPEN-ENDED QUESTIONS)

INSTRUCTIONS

There are five machine-scored open-ended questions each with a value of 1 mark in this section of the test. All numbers used in the questions are to be considered as the results of measurements.

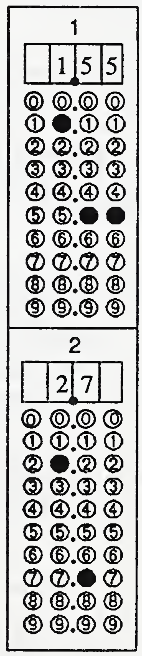
Read each question carefully.

Solve each question and write your answer to the appropriate number of significant figures.

Transfer your answer to the appropriate box on the answer sheet provided. Darken one circle in each column as necessary in order to record the answer to the correct number of significant figures, as illustrated below. USE AN HB PENCIL ONLY.

Sample Questions and Solutions

Answer Sheet



1) If the angle of incidence is 47.3° and the angle of refraction is 28.3°, the index of refraction is __________.

$$n = \frac{\sin \theta_1}{\sin \theta_2}$$

$$n = \frac{\sin 47.3°}{\sin 28.3°} = 1.55$$

RECORD 1.55

2) A microwave of wavelength 11 cm has a frequency of $b \times 10^9$ Hz. The value of b is __________.

$$f = c/\lambda$$

$$= (3.00 \times 10^8 \text{ m/s})/(0.11 \text{ m})$$

$$f = 2.727... \times 10^9 \text{ Hz}$$

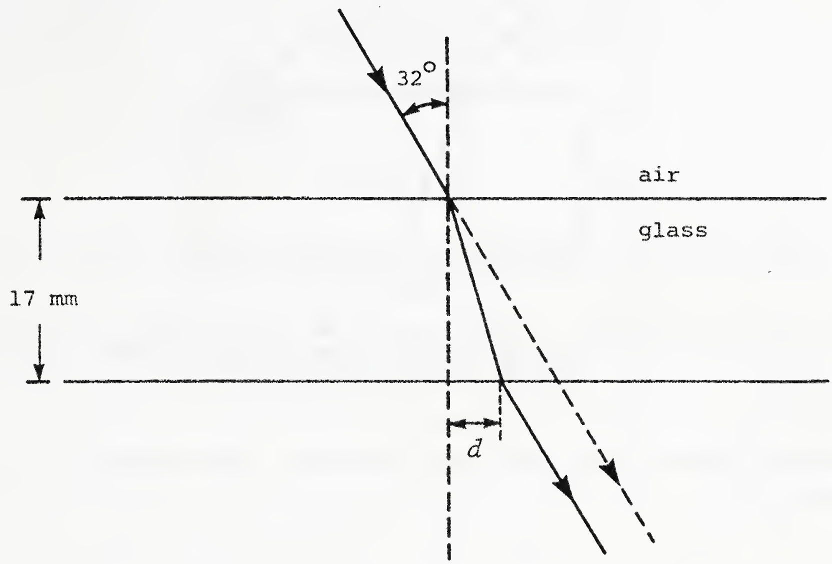
RECORD 2.7

The answers 2.70, 2.72, and 2.73 will all be marked as incorrect, as the data given are to two significant figures only.

If you wish to change an answer, please erase your first mark completely.

WHEN YOU HAVE COMPLETED PART B, PLEASE PROCEED DIRECTLY TO PART C

Use the following information to answer question 1.

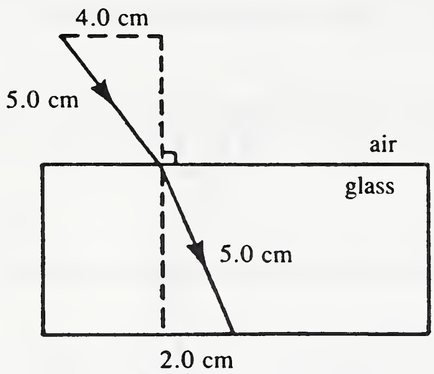


A glass plate that is 17 mm thick has a refractive index of 1.5. A ray of light passing through air is incident on the plate at an angle of 32°.

1. Where the ray leaves the glass, the horizontal distance *d* between the emerging ray and the normal is __________ mm.

RECORD THE ANSWER ON THE ANSWER SHEET

Use the following information to answer question 2.



A ray of light travels from air into glass.
This diagram is not to scale.

2. The speed of light in the glass is $b \times 10^{8}$ m/s. The value of b is __________.

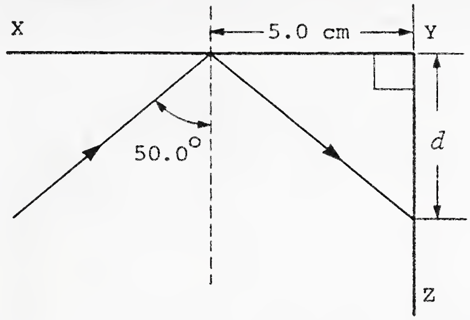
RECORD THE ANSWER ON THE ANSWER SHEET

---

3. If a diffraction grating with 3.00×10^{5} lines/m gives a first-order bright image at an angle of 10.0° on a screen that is 5.00 m away, then the wavelength of the light is measured to be $b \times 10^{-7}$ m. The value of b is __________.

RECORD THE ANSWER ON THE ANSWER SHEET

Use the following information to answer question 4.



Two plane mirrors XY and YZ are at right angles to each other.

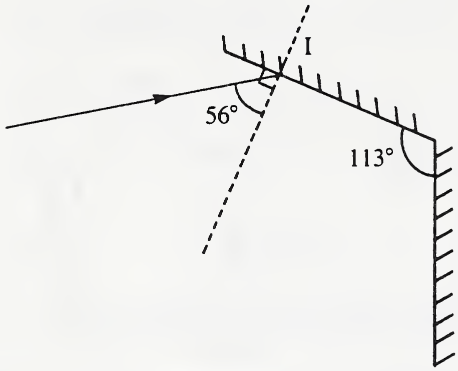
4. A ray of light strikes mirror XY 5.0 cm from Y. The reflected ray strikes mirror YZ at a distance *d* of __________ cm from Y.

RECORD THE ANSWER ON THE ANSWER SHEET

5. A laser beam is transmitted to a satellite and back. If the time of travel there and back is 1.23×10^{-2} s, the distance between the satellite and the surface of the Earth, expressed in scientific notation, is $b \times 10^{w}$ m. The value of *b* is __________.

RECORD THE ANSWER ON THE ANSWER SHEET

Use the following information to answer question 6.



A ray of light hits the first mirror at point I and is reflected to the second mirror, where it is reflected again.

6. If the angle of incidence is 56° and the angle between the mirrors is 113°, then the angle between the final reflected ray and the second mirror is __________°.

RECORD THE ANSWER ON THE ANSWER SHEET

7. In glass (n = 1.53), a certain infra-red source has a wavelength of 8.00×10^{-7} m. Its frequency is $b \times 10^{14}$ Hz. The value of b is __________.

RECORD THE ANSWER ON THE ANSWER SHEET

8. A polarizing filter is set so that the previously polarized light passing through it has MAXIMUM brightness. In order to have the light passing through it of MINIMUM brightness, the filter must be rotated by __________ degrees.

RECORD THE ANSWER ON THE ANSWER SHEET

9. Two negatively charged spheres placed 1.00 m apart repel each other with a force of 10.2 N. If the distance between the spheres is increased to 3.00 m and the charge on each sphere is increased by a factor of exactly 4, the force of repulsion would be expected to become _________ N.

RECORD THE ANSWER ON THE ANSWER SHEET

10. The electric field between two parallel plates that are 5.0 cm apart is 3.0×10^2 N/C. The potential difference across the plates is __________ V.

RECORD THE ANSWER ON THE ANSWER SHEET

11. The acceleration of an electron in an electric field with a strength of 7.04 N/C is $w \times 10^b$ m/s^2, when expressed in scientific notation. The value of the exponent b is __________.

RECORD THE ANSWER ON THE ANSWER SHEET

12. If a flashlight bulb draws 0.25 A from a 3.0 V battery, the power supplied is __________ W.

RECORD THE ANSWER ON THE ANSWER SHEET

13. If a proton is accelerated from rest through a potential difference of 1.10×10^6 V, it attains a final speed, expressed in scientific notation, of $b \times 10^w$ m/s. The value of b is __________.

RECORD THE ANSWER ON THE ANSWER SHEET

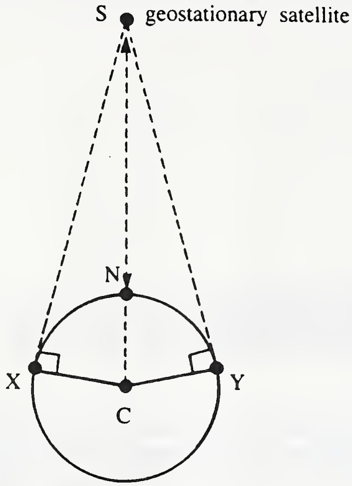
14. If a proton moves perpendicularly across a magnetic field of strength 2.5×10^{-2} T at a speed of 5.3×10^6 m/s, it would experience a force, expressed in scientific notation, of $b \times 10^w$ N. The value of b is __________.

RECORD THE ANSWER ON THE ANSWER SHEET

15. A proton moving at 2.6×10^5 m/s perpendicularly to a magnetic field of 1.1 T experiences a deflecting force that causes it to orbit in a circle. The radius of the orbit, expressed in scientific notation, is $b \times 10^w$ m, where b is __________.

RECORD THE ANSWER ON THE ANSWER SHEET

Use the following information to answer question 16.



$XC = 6.4 \times 10^3$ km

$SN = 3.6 \times 10^4$ km

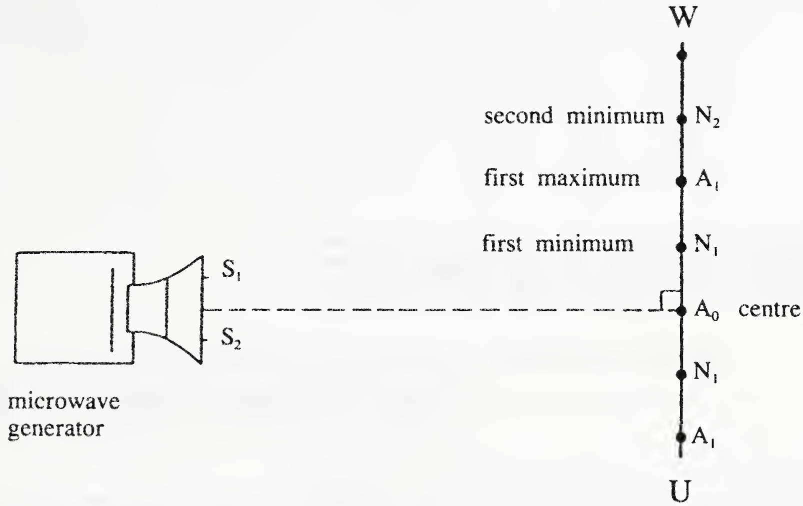
A geostationary satellite in an equatorial orbit is used to relay a signal from station X to station Y. C is the centre of the Earth, and SNC is a straight line.

16. A microwave signal from station X will reach station Y in __________s.

RECORD THE ANSWER ON THE ANSWER SHEET

Use the following information to answer question 17.

Microwave Double-Slit Experiment



A two-source extension is placed over the horn of a microwave generator that transmits radiation with a frequency of 5.0×10^{10} Hz. This procedure converts the generator into a double-slit apparatus. A detector moves along line UW. This diagram is NOT drawn to scale.

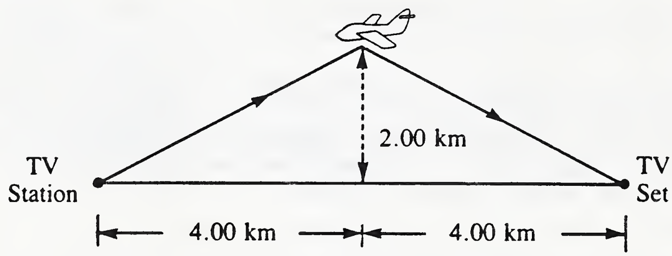
17. If S_1 and S_2 are separated by 0.27 m and A_1 is 0.36 m from A_0, the distance from the horn to A_0 is __________ m.

RECORD THE ANSWER ON THE ANSWER SHEET

18. A radio station broadcasts on a wavelength of 5.0×10^2 m. The frequency of the station's radio waves is _________ MHz.

RECORD THE ANSWER ON THE ANSWER SHEET

Use the following information to answer question 19.



A TV set receives a signal by direct transmission and by reflection from a plane.

19. The time delay between the direct signal and the reflected signal is $b \times 10^{-6}$ s. The value of b is _________.

RECORD THE ANSWER ON THE ANSWER SHEET

20. During electrolysis, the mass of aluminum, expressed in scientific notation, that would be deposited from a solution of Al^{3+} ions in 15.3 min by a current of 0.901 A is $b \times 10^{w}$ g. The value of b is __________.

RECORD THE ANSWER ON THE ANSWER SHEET

21. In Millikan's oil drop experiment, a charged particle having a mass of 6.4×10^{-16} kg is accelerating upwards at 2.2 m/s^2 under the influence of an electric field between two horizontal plates having a separation of 5.0 cm. If the potential difference across the plates is 120 V, the charge on the particle is __________ elementary charges.

RECORD THE ANSWER ON THE ANSWER SHEET

Use the following information to answer questions 22 and 23.

When white light is shone through hydrogen gas, a dark line in the absorption spectrum, corresponding to the red line in the emission spectrum, is observed. This red line is produced by the transition of an electron from the n = 3 to the n = 2 Bohr orbit.

22. The energy of the absorbed photon is __________ eV.

RECORD THE ANSWER ON THE ANSWER SHEET

23. The frequency of the absorbed red light is $b \times 10^{14}$ Hz. The value of b is __________.

RECORD THE ANSWER ON THE ANSWER SHEET

24. When zinc (W = 4.03 eV) in a photoelectric cell is irradiated by radiation of frequency 4.52×10^{15} Hz, the maximum kinetic energy of photoelectrons leaving the cell is $b \times 10^{-18}$ J. The value of b is __________.

RECORD THE ANSWER ON THE ANSWER SHEET

25. If an object has a mass of 4.0×10^{-17} kg when travelling at a speed of $0.694c$ its rest mass is $b \times 10^{-17}$ kg. The value of b is __________.

RECORD THE ANSWER ON THE ANSWER SHEET

26. If a proton has a relativistic mass of 2.1×10^{-27} kg, its speed is $b \times 10^{8}$ m/s. The value of b is __________.

RECORD THE ANSWER ON THE ANSWER SHEET

27. The momentum of a photon with 5.1×10^{-19} J of energy, expressed in scientific notation, is $w \times 10^{-b}$ kg•m/s. The value of the exponent b is __________.

RECORD THE ANSWER ON THE ANSWER SHEET

28. The speed, expressed in scientific notation, of an object that has a mass of 2.2×10^{-20} kg and an associated wavelength of 5.1×10^{-18} m is $b \times 10^{w}$ m/s. The value of b is __________.

RECORD THE ANSWER ON THE ANSWER SHEET

29. The de Broglie wavelength, when expressed in scientific notation, of an electron that has been accelerated from rest through a potential difference of 5.0×10^1 V, is $b \times 10^w$ m. The value of b is __________.

RECORD THE ANSWER ON THE ANSWER SHEET

30. If the uncertainty in the speed of a 400 kg space probe is 0.5 m/s, the theoretical minimum uncertainty in its position is in the order of 10^{-b} m. The value of the exponent b is __________.

RECORD THE ANSWER ON THE ANSWER SHEET

ITEM INFORMATION SHEET

Item	Key	Multiple Choice Difficulty	Source
1	6.4 6.5	0.768	June'87 #8
2	1.5	0.769	June'88 #5
3	5.78 5.79 5.87 5.88	0.697	June'87 #11
4	4.2	0.854	June'88 #4
5	1.85	0.517	Jan'86 #2
6	33.	0.457	Jan'84 #5
7	2.45 2.46	0.759	June'88 #10
8	90. 90.0 90.00	0.771	Jan'86 #10
9	18.1 18.2	0.655	Jan'89 #14
10	15.	0.834	Jan'88 #21
11	12.	0.796	June'87 #16
12	0.75	0.960	Jan'86 #19
13	1.45	0.505	Jan'84 #17
14	2.2	0.929	Jan'88 #26
15	2.5	0.591	Jan'84 #23

Item	Key	Multiple Choice Difficulty	Source
16	0.28	0.666	June'87 #28
17	16.	0.702	June'88 #34
18	0.60	0.879	Jan'84 #35
19	3.1 3.13 3.14 3.15	0.617	Jan'84 #32
20	7.71*	0.844	Jan'86 #38
21	20.	0.353	Jan'84 #46
22	1.89 1.90	0.646	Jan'86 #45
23	4.56 4.57 4.58 4.59	0.703	Jan'86 #46
24	2.35*	0.656	Jan'84 #37
25	2.9	0.733	Jan'88 #48
26	1.8	0.644	June'87 #49
27	27.	0.830	Jan'88 #50
28	5.9	0.791	June'87 #51
29	1.7	0.705	Jan'88 #54
30	37.	0.645	Jan'89 #49

Notes:

Questions 11, 27, and 30 will be marked correct with trailing zeros included, even through the answer is a whole number.

Questions 18 and 22 will be marked incorrect if the trailing zero (depending on method used in 22) is not included.

For question 21, an integral answer is required to demonstrate understanding of the quantum nature of electrical charge.

*For explanation of these single answers refer to page 27 for question 20 and to page 30 for question 24.

SOLUTIONS TO QUESTIONS HAVING MULTIPLE CORRECT ANSWERS

Solution to question 1

$$n_R \bullet \sin \Theta_R = n_i \bullet \sin \Theta_i$$

$$\Theta_R = \sin^{-1} (\sin 32°/1.5)$$

$$\Theta_R = 20.69°$$

$$\sin \Theta_R = d/\text{thickness}$$

$$d = (17 \text{ mm})(\tan 20.69°) = 6.42 \text{ mm}$$

$$d = 6.4 \text{ mm}$$

Note: If the angle is rounded to two significant digits ($\Theta_R = 21°$), an answer $d = 6.5$ mm is obtained. Although acceptable, this answer is less desirable as it involves a calculation based on a prematurely rounded value.

Bubble 6.4 or 6.5

Solution to question 3

Method 1: diffraction grating

$$\lambda = (d \cdot \sin \theta)/n$$

$$= \sin 10.0°/(3.00 \times 10^5/\text{m})$$

$$\lambda = 5.79 \times 10^{-7} \text{ m}$$

Note: If d is calculated first by taking the reciprocal of 3.00×10^5 lines/m and rounding to 3 significant figures, an answer of $\lambda = 5.78 \times 10^{-7}$ m is obtained using the same method as above. Although acceptable, this answer is less desirable as it involves a calculation based on a prematurely rounded value.

Bubble 5.78 or 5.79

Method 2: double slit

$$x = \ell \cdot \tan \theta$$

$$= (5.00 \text{ m})(\tan 10.0°)$$

$$= 0.8816 \text{ m}$$

$$x = 0.882 \text{ m}$$

$$\lambda = dx/n\ell$$

$$= 0.882 \text{ m}/[(3.00 \times 10^5/\text{m})(5.00 \text{ m})]$$

$$\lambda = 5.88 \times 10^{-7} \text{ m}$$

Note: If d is calculated first and rounded to 3 significant figures ($d = 3.33 \times 10^{-6}$ m) as in method 1, and answer of $\lambda = 5.87 \times 10^{-7}$ m is obtained. Although acceptable, this answer is less desirable for the same reason as above.

Bubble 5.87 or 5.88

Both methods are equally valid.

Solution to question 7

$$\lambda_{air} = \lambda_{glass} \bullet n_{glass}$$

$$= (8.00 \times 10^{-7}\ \mathrm{m})(1.53)$$

$$\lambda_{air} = 1.224 \times 10^{-6}\ \mathrm{m}$$

$$f = c/\lambda_{air}$$

$$= (3.00 \times 10^{8}\ \mathrm{m/s})/(1.224 \times 10^{-6}\ \mathrm{m})$$

$$f = 2.451 \times 10^{14}\ \mathrm{Hz}$$

$$f = 2.45 \times 10^{14}\ \mathrm{Hz}$$

Note: If the wavelength is rounded to three significant digits, $\lambda_{air} = 1.22 \times 10^{-6}$ m, then an answer of $f = 2.46 \times 10^{14}$ Hz is obtained. Although acceptable, this answer is less desirable as it incorporates a prematurely rounded intermediate value.

Bubble 2.45 or 2.46

Solution to question 9

Method 1:

$$F_2 = F_1 \left[\frac{(q_A q_B)_2}{(q_A q_B)_1}\right] \left[\left(\frac{d_1}{d_2}\right)^2\right]$$

$$= 10.2 \text{ N } (4^2/3.00^2)$$

$$F_2 = 18.1 \text{ N}$$

Bubble 18.1

Method 2:

$$q_A q_B = FR^2/k = 1.1346 \times 10^{-9} \text{ C}^2$$

$$F_2 = k(4q_A)(4q_B)/R^2$$

$$= (8.99 \times 10^9 \text{ N·m}^2/\text{C}^2)(16)(1.1346 \times 10^9 \text{ C}^2)/(3.00 \text{ m})^2$$

$$F_2 = 18.1 \text{ N}$$

Note: Students who make an assumption regarding the relationship between q_A and q_B (e.g. $q_A = q_B = 3.37 \times 10^{-5}$ C), and prematurely round the value to three significant figures, will obtain an answer of $F = 18.2$ N. This procedure is barely acceptable.

Bubble 18.1 or 18.2

Both methods are equally valid for an answer of 18.1 N; however, the answer 18.2 N is barely acceptable.

Solution to question 19

distance by reflection $d_R = 2\sqrt{(4.00\ \text{km})^2 + (2.00\ \text{km})^2}$

$d_R = 8.944$ km

direct distance $d_D = 8.00$ km

path difference $= d_R - d_D = 0.944$ km

time delay = path difference/c

$= 0.944\ \text{km}/(3.00 \times 10^5\ \text{km/s})$

$= 3.147 \times 10^{-6}$ s

time delay $= 3.1 \times 10^{-6}$ s

Note: Because of the subtraction of distances to obtain the path difference, the number of significant figures in the final answer is two. Students who are unaware of the rule of precision that governs addition and subtraction operations may use the input data to determine the number of significant figures allowed in the final answer. In this case, depending on how partial answers are rounded, students may obtain answers of $(3.13 \text{ or } 3.15) \times 10^{-6}$ s. Although less desirable, these answers will be accepted.

Bubble 3.1, 3.13, or 3.15

Solution to question 20

Method 1:

$$m = ItA/(Fv)$$

$$= \frac{(0.901\ \text{C/s})(15.3\ \text{min})(60\ \text{s/min})(26.98\ \text{g/mol})}{(9.65 \times 10^{4}\ \text{C/mol})}$$

$$m = 7.71 \times 10^{-2}\ \text{g}$$

Method 2:

$$Al^{3+} + 3e^{-} \rightarrow Al$$

$$m_{Al} = n_{Al} \cdot M_{Al}$$

$$n_{Al} = n_{e}/3$$

$$n_{e} = It/F$$

$$= \frac{(0.901\ \text{C/s})(15.3\ \text{min})(60\ \text{s/min})}{(9.65 \times 10^{4}\ \text{C/mol})}$$

$$n_{e} = 8.571 \times 10^{-3}\ \text{mol}$$

$$n_{Al} = (8.571 \times 10^{-3}\ \text{mol})/3$$

$$n_{Al} = 2.857\ \text{mol}$$

$$m_{Al} = (2.857 \times 10^{-3}\ \text{mol})(26.98\ \text{g/mol})$$

$$m_{Al} = 7.71 \times 10^{-2}\ \text{g}$$

Note: Premature internal rounding of $n_{Al} = 2.86 \times 10^{-3}$ mol will produce an answer of $m_{Al} = 7.72 \times 10^{-2}$ g. This answer is not acceptable as it is obtained from an inappropriately rounded intermediate value.

Bubble 7.71

Solution to question 22

Method 1:

$$E_n = E_1/n^2$$

$$E_3 = -13.6\ \text{eV}/9 = -1.511\ \text{eV}$$

$$E_2 = -13.6\ \text{eV}/4 = -3.400\ \text{eV}$$

$$\text{photon energy } E = -\Delta E = -(E_f - E_i)$$

$$= -(-3.400\ \text{eV} + 1.511\ \text{eV})$$

$$E = 1.89\ \text{eV}$$

Note: Solutions may be done in J rather than eV with the answer converted to eV at the end. Such solutions also have answer of 1.89 eV.

Bubble 1.89

Method 2:

$$1/\lambda = R_H\ [(1/n_f^2) - (1/n_i^2)]$$

$$= R_H\ [(1/4) - (1/9)]$$

$$= 5R_H/36$$

$$\lambda = 36/(5 \times 1.10 \times 10^7/\text{m})$$

$$\lambda = 6.545 \times 10^{-7}\ \text{m} = 6.55 \times 10^{-7}\ \text{m}$$

$$E = hc/\lambda$$

$$= (6.63 \times 10^{-34}\ \text{J}\bullet\text{s})(3.00 \times 10^8\ \text{m/s})/(6.55 \times 10^{-7}\ \text{m})$$

$$E = (3.04 \times 10^{-19}\ \text{J})/(1.60 \times 10^{-19}\ \text{J/eV})$$

$$E = 1.90\ \text{V}$$

Note: The trailing zero MUST be included for an answer correct to 3 significant figures.

Bubble 1.90

Both methods are equally valid.

Solution to question 23

Method 1: following from #22

$$f = E/h$$

$$= (1.89 \text{ eV})(1.6 \times 10^{-19} \text{ J/eV})/(6.63 \times 10^{-34} \text{ J}\cdot\text{s})$$

$$f = 4.56 \times 10^{14} \text{ Hz}$$

Note: Other variations of this solution include using E = 1.90 eV and/or $h = 4.14 \times 10^{-15}$ eV•s. These variations produce answers of 4.59×10^{14} Hz and 4.57×10^{14} Hz.

Bubble 4.56, 4.57, or 4.59

Method 2: using the Rydberg equation

$$f = c/\lambda \text{ and } 1/\lambda = R_H[(1/4) - (1/9)]$$

$$f = (3.00 \times 10^{8} \text{ m/s})/(6.55 \times 10^{-7} \text{ m})$$

$$f = 4.58 \times 10^{14} \text{ Hz}$$

Bubble 4.58

Both methods are equally valid.

Solution to question 24

$$E_{k\ max} = hf - W$$

$$= (6.63 \times 10^{-34}\ J/Hz)(4.52 \times 10^{15}\ Hz) - (4.03\ eV)(1.60 \times 10^{-19}\ J/eV)$$

$$= (2.997 \times 10^{-18}\ J) - (6.448 \times 10^{-19}\ J)$$

$$E_{k\ max} = 2.35 \times 10^{-18}\ J$$

Note: Solutions done using $h = 4.14 \times 10^{-15}$ eV/Hz produce the same answer as above.

Solutions which round intermediate answers to $hf = 3.00 \times 10^{-18}$ J and/or $W = 6.45 \times 10^{-19}$ J produce an answer of $E_{k\ max} = 2.36 \times 10^{-18}$ J. This answer is not acceptable as it is obtained from an inappropriately rounded intermediate value.

Bubble 2.35

ANSWER SHEET WITH SOLUTIONS DISPLAYED

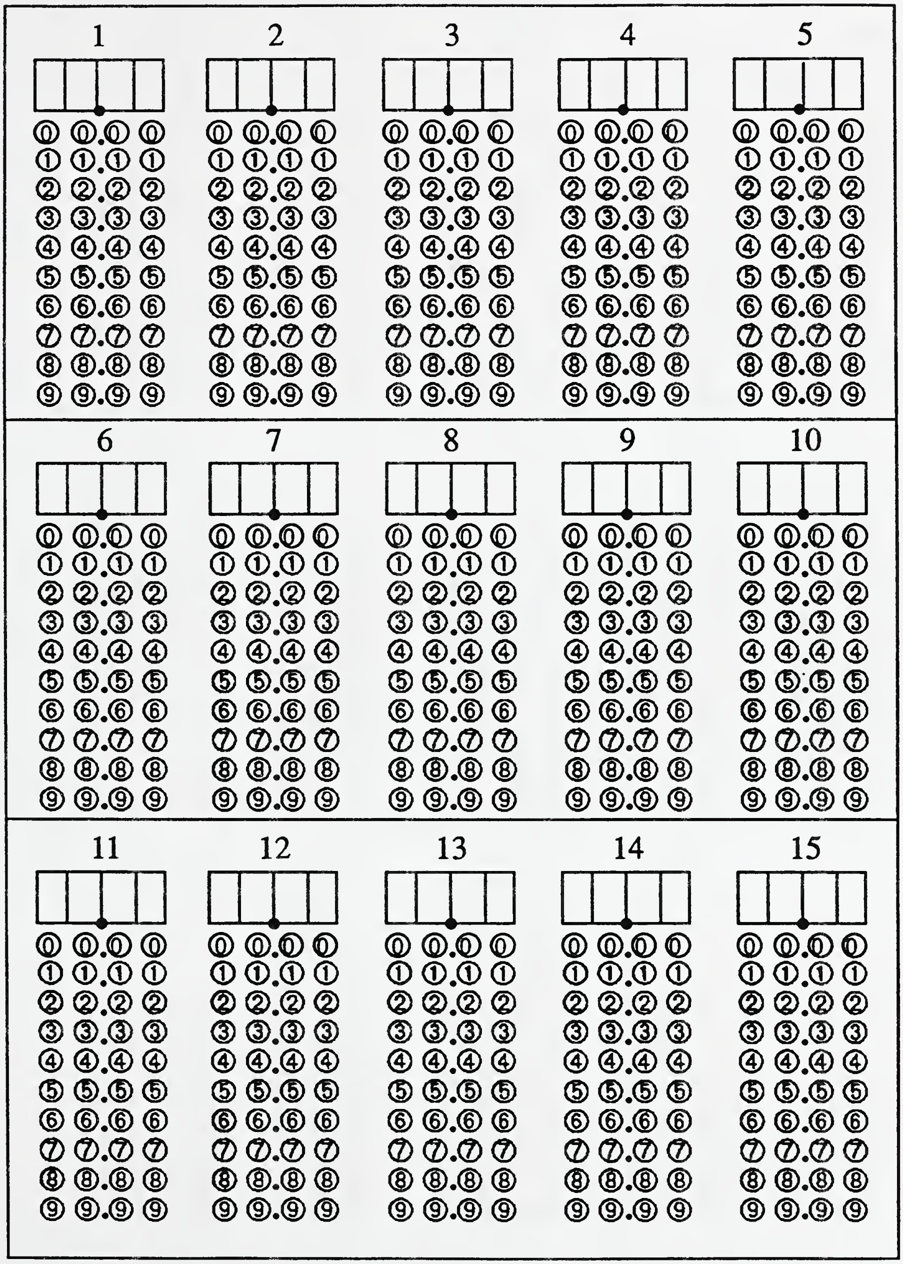
1	2	3	4	5
6.4	1.5	5.79	4.2	1.85

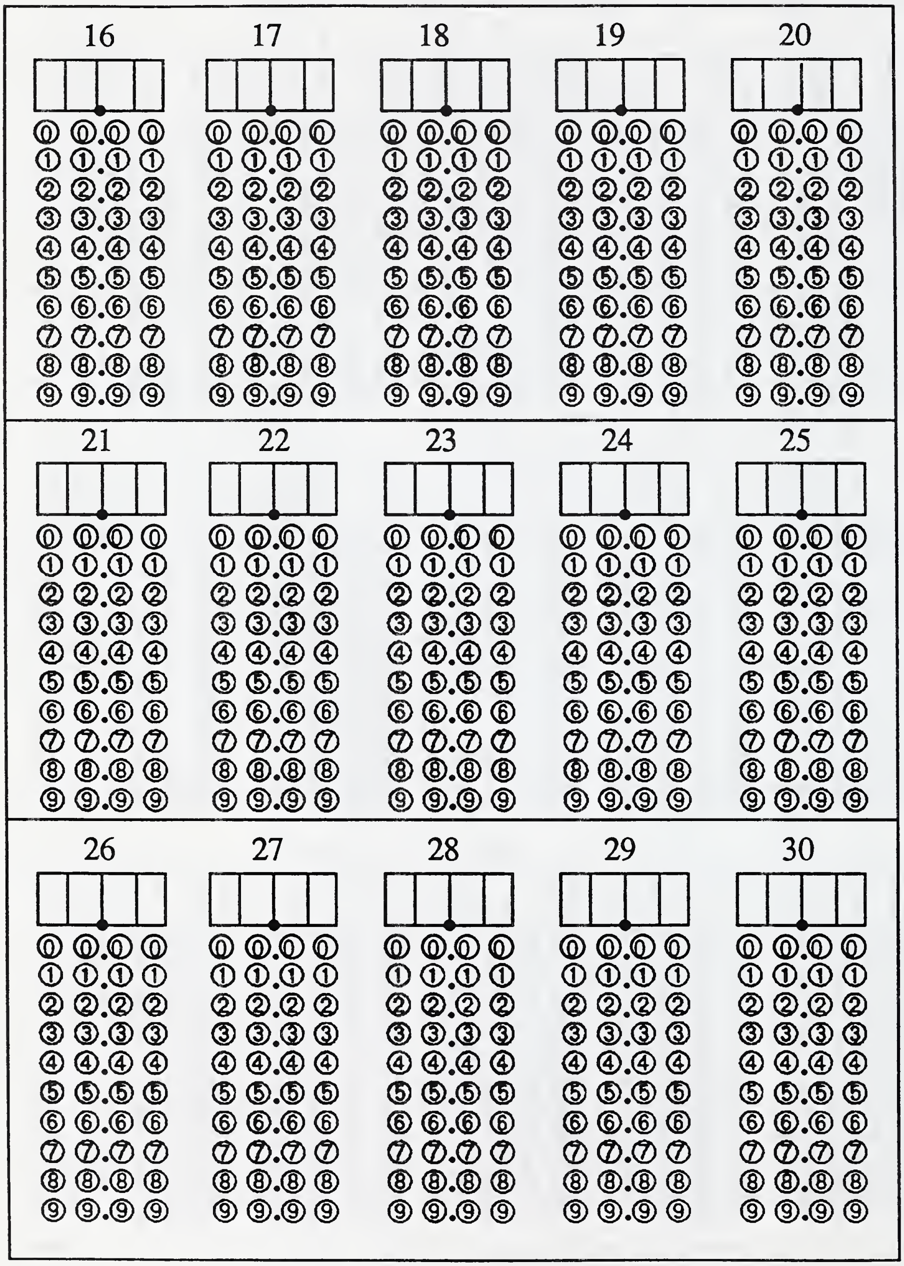
6	7	8	9	10
33.	2.45	90.	18.1	15.

11	12	13	14	15
12.	0.75	1.45	2.2	2.5

16		0	2	8
17	1	6		
18		0	6	0
19		3	1	
20		7	7	1
21	2	0		
22		1	8	9
23		4	5	6
24		2	3	5
25		2	9	
26		1	8	
27	2	7		
28		5	9	
29		1	7	
30	3	7		

SAMPLE ANSWER SHEET, BLANK FOR STUDENT USE

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